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METHODS OF MAKING ALUMINUM BRONZE CASTINGS

(MATERIAL SECTION REPORT No. 174)

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METHODS OF MAKING ALUMINUM BRONZE CASTINGS.

PURPOSE.

This investigation was undertaken in response to requests for aluminum bronze castings with the following objects in view:

1. To determine the mechanical properties and casting qualities of several compositions of aluminum bronze with varying iron and aluminum content.
2. To obtain experience in the foundry so as to be prepared to make castings of these alloys.

CONCLUSIONS.

1. The best mechanical properties were obtained in an alloy containing 7.98 per cent aluminum, 3.22 per cent iron, balance copper. This alloy in the "As cast" condition showed the following average properties:

Yield point, pounds per square inch	28,000
Ultimate strength, pounds per square inch	79,000
Elongation, per cent	45
Charpy impact, foot-pounds	35
Brinell hardness, 500 kg	130
Scleroscope	30
Rockwell No	73
Specific gravity	7.64
Modulus of elasticity	17,500,000

2. It was found that these alloys with proper precautions in regard to melting practice, and the same general methods of gating employed for manganese bronze, can be successfully cast. A maximum furnace temperature of 2,200° F. with a pouring temperature of 2,000° F. for average castings is recommended. Considerable care should be exercised to prevent oxidation by keeping the melt covered with a liberal covering of charcoal at all times. Large gates and ample risers are necessary, and bottom pouring through a skim gate which allows the metal to enter the mold with the least agitation possible is desirable.

3. These alloys are difficult to machine due to their great hardness and toughness, but are to be recommended in spite of this drawback where high strength and resistance to shock are required in a casting.

MATERIAL.

RAW MATERIALS.

The copper used for this investigation was foundry melt No. 856, of which five different ingots, weighing from 20 to 25 pounds each, were analyzed with the following results in per cent purity: 99.81, 99.81, 99.89, 99.83, 99.78. This is slightly under the Air Service specification, which requires a purity of 99.88 per cent.

The aluminum ingot used (melt No. 1045) was purchased from the British Aluminum Co. The analysis obtained by the Chemistry branch was as follows:

Copper	0.07
Silicon	.37
Iron	.47

The iron used was a light gauge tinned sheet obtained from stock.

The aluminum bronze ingot purchased from the Lumen Bearing Co. (melt No. 692) and used for comparative purposes was found on analysis to contain:

Copper	89.60
Aluminum	8.49
Iron	1.27
Zinc	.53
Silicon	.09
Tin	Nil.
Lead	Nil.

PROCEDURE.

PREPARATION OF HARDENERS.

The iron was introduced in the form of a copper-aluminum-iron hardener which was prepared by heating the iron and copper together in the Iler furnace and the aluminum in the Monarch furnace. When the copper was melted and brought to a good heat, the molten aluminum was poured into it with frequent stirring. The heat thus generated was sufficient to melt the iron and insure thorough solution. The hardener, melt No. 472, which was already on hand, had the following composition:

	As mixed.	Analysis.
Aluminum	67	65.18
Iron	11	13.85
Copper	22	20.97

The hardener, melt No. 1191, was made especially for this investigation with the following composition:

	As mixed.	Analysis.
Copper	60	58.86
Iron	20	20.90
Aluminum	20	20.24

Lumen Bearing Co. ingot:

Melt No.	722	1175
Total weight, pounds	120	80
Time in furnace, minutes	180	65
Maximum furnace temperature, °F	2,000	2,030
Pouring temperature, °F	1,950	1,980

Melted under a thick covering of charcoal.

The purpose of melt No. 722 was to obtain comparative test results from four different methods of casting test bars, sketches of which are included. Two molds (six bars) were cast according to pattern TB-1 (fig. 18). They were tested "as cast" without any machining. Two molds (six bars) TB-1A were cast in the same manner as TB-1 except that they were one-eighth inch larger in diameter, to allow for machining. They were tested in wedge grips after machining. Three molds of pattern TB-2A and TB-2B (figs. 19 and 20) were cast with wedge risers (three bars each). These patterns are similar except in the width of web joining the specimen and riser. TB-2A has a one-eighth-inch web and TB-2B a one-fourth-inch web. These bars were machined to size and tested in self-aligning adapters. One mold (one bar) of pattern TB-2S (fig. 21) was cast with a 7-inch riser. This bar was also machined to size and tested in self-aligning adapters.

EXPERIMENTAL MELTS.

Melt No.	1177	1180	1192	1195	1213
Aluminum	8	8	8	8	10
Iron	0	1.7	3	4	3
Copper	Bal.	Bal.	Bal.	Bal.	Bal.
Total weight, pounds	143.5	170	198	195.5	202.9
Time in furnace, minutes	165	210	180	220	215
Maximum furnace temperature, °F	2,150	2,070	2,220	2,200	2,160
Pouring temperature, °F	2,040	2,000	2,040	1,970	1,980
Hardener, melt No.	None.	472	1,191	1,191	1,191

In mixing these melts the copper was first melted down and brought to a good heat and then the iron hardener and additional aluminum held under the surface until thoroughly melted. Care was taken to prevent oxidation by a thick covering of charcoal and the metal was thoroughly stirred to insure complete mixing.

In all of these melts the following test bars were cast: Three 0.505 inch diameter tension specimens, pattern TB-2B. One modulus of elasticity tension specimen, pattern TB-8. Three porosity cups, pattern PC-2. One bar, 2¼ inches diameter by 12 inches long, to compare size of pipe formed. Several sample castings from patterns in foundry, in order to compare casting qualities of the different alloys.

METHODS OF TESTING.

The physical tests were performed according to standard procedure and require little comment except in respect to the modulus of elasticity tests and the impact tests. The modulus of elasticity tests were made on specimens three-fourths inch in diameter, with 8-inch gauge length. The deformation readings were taken on a Ewing extensometer. The Charpy impact tests were made in a standard American made Charpy impact machine on a 10 by 10 millimeter square specimen with the notch 2 millimeters in diameter and 5 millimeters deep.

RESULTS.

The results of the physical tests of these alloys are summarized in five tables and two curve sheets. The chemical analyses are given in Table 6. The report is illustrated by 1 photograph and 13 microphotographs.

DISCUSSION OF RESULTS.

METHOD OF CASTING TEST BARS.

The results of these tests as given in Table 1 indicate that the highest tensile strength and elongation are obtained from method of pattern TB-1. The high strength according to this method is accounted for by the strength of the skin which was not removed. A comparison of these results with the results of pattern TB-1A, which is similar in every respect except the bars are one-eighth inch larger in diameter, showed that about 5,000 to 6,000 pounds per square inch may be attributed to the "skin effect." Of the "machined" specimens, pattern TB-2B seems to give the highest, and at the same time, most consistent results. It is evident that the feeding action of the risers along the full length of the bar is counterbalanced by the slow rate of cooling due to the greater mass so that the effect of feeding in this manner is not nearly as pronounced as it is in the case of manganese-bronze test bars. For instance, pattern TB-2S which gives the highest results in manganese bronze, gave the lowest results in aluminum bronze. The microphotographs in Figures 9 to 14, inclusive, illustrate the effect of slow cooling, due to the greater mass in these test bars and explain the cause of the low tensile strength obtained on specimen TB-2S. Although these tests are not conclusive, it seems desirable to use pattern TB-2B for this alloy because of its very high shrinkage.

THE EFFECT OF IRON ON THE ALLOY CONTAINING 8 PER CENT ALUMINUM.

The effect of iron is shown graphically on curve sheets 1 and 2 (figs. 16 and 17). Referring first to curve sheet 1, it will be noted that iron very markedly raises the tensile strength and hardness and decreases the elongation. The Charpy impact value is lowered 50 per cent by the addition of 1.7 per cent iron, but this is probably accounted for by the fact that the specimens containing no iron were so very ductile that they were merely bent in the test and the friction of dragging the bars past the vise gave a fictitiously high value. The alloy without iron was so soft that two of the TB-2B specimens were spoiled in machining. The Charpy impact value of 35-foot pounds, obtained with 3 per cent iron, is very good. The effect of iron on the modulus of elasticity and proportional limit is well illustrated in curve sheet 2. Three per cent iron more than doubles the proportional limit and raises the modulus appreciably.

With this alloy, the addition of 3 per cent iron seems to be highly beneficial in regard to the mechanical properties.

COMPARISON OF THE 8 AND 10 PER CENT ALUMINUM ALLOYS.

A comparison of melts 1213 and 1192 shows that with 9.70 per cent aluminum and 3.20 per cent iron the tensile strength and elongation are both less than with the alloy

of 7.98 per cent aluminum and 3.22 per cent iron. It is therefore concluded that in an aluminum bronze containing substantial percentages of iron the aluminum content should not be much over 8 per cent. The best mechanical properties of the series were obtained with the above alloy of 7.98 per cent aluminum and 3.22 per cent iron. The appearance of the tension specimens after fracture is shown in Figure 1.

POROSITY TESTS.

The porosity test results are given in Table 5. The method employed in these tests is explained in detail in Material Section Report No. 160, Serial No. 1882. It will be noted that in general the series of alloys showed up very well in this test and that where leaks occurred they were due to casting defects rather than an inherent quality in the metal. However, it is a matter of practical experience that aluminum-bronze castings are very difficult to make tight against hydraulic or air pressure.

CASTING QUALITIES.

As previously stated, castings were made from several patterns on hand in the foundry in each of the experimental melts cast in order to investigate the casting qualities of these alloys, and in addition a bar 2½ inches in diameter by 12 inches long was cast horizontally with a 2-inch diameter pouring head at one end and a 2-inch diameter riser at the other end, both being joined to the bar by heavy gates. Both the riser and pouring head showed good shrinkage in the top and the bar appeared sound in other respects. These bars were then sawed into 1-inch thick sections and they were found to contain pipes extending from the gates at the pouring end of the bar and in one instance from the riser end. The extent of this pipe is given in the following tabulation:

Melt No.	Length of pipe from pouring head.	Length of pipe from riser.
	Inches.	*Inches.*
1177	4¾	4
1180	7¾	0
1192	8¾	0
1195	9	0
1213	8½	0

This tabulation gives an indication of the high shrinkage of all of these alloys. It has been stated by H. Rix and H. Whitaker (see reference) that iron forms a refractory skeleton which reduces shrinkage and produces a fine grain. Although our tests indicated that iron has a tendency to form a fine-grain structure, there was no indication that it reduced the shrinkage of the alloys. It was, however, found that by methods of gating similar to those employed in the production of manganese bronze castings it was possible to very successfully cast the aluminum bronzes, and the castings had a beautiful golden color and appeared sound if the shrinkage was properly taken care of. It is necessary in melting this metal to use the utmost precaution to prevent oxidation, as the oxidation of aluminum produces hard particles of alumina which seriously interfere with machining.

MACHINING PROPERTIES.

The combined toughness and hardness of aluminum bronze makes it very difficult to machine, and this one factor has been the chief cause for the rather limited use which has been made of it. The iron considerably increases the Brinell hardness of the alloys and probably makes them more difficult to machine. Considerable difficulty was experienced in the foundry in removing the gates and risers by means of the band saw, used for all other nonferrous alloys. A few heavy gates were sufficient to spoil a new saw blade.

HEAT TREATMENT.

That the aluminum bronzes are subject to heat treatment in much the same manner as steel is a matter of common knowledge, and although few experiments have been made in this laboratory in regard to the heat treatment, it seems advisable to mention the hardness obtained in the several heat treatments which have been carried out. A section of an extruded bar (90 per cent copper, 10 per cent aluminum) 1½ inches in diameter by 2½ inches long was subjected to several heat treatments with the results given below:

Time at temperature.	Temperature (° F.) (water quenched).	Brinell hardness (3,000 kg.).
As received		150
One-half hour	1,517	163
One-half hour	1,716	153
1 hour	1,780	154

A disk 3½ inches in diameter by 1 inch thick of melt 1213 (copper 87.10 per cent, iron 3.20 per cent, aluminum 9.7 per cent) was quenched in water after one-half hour at 1,472° F. with the following results:

	Brinell.		Scleroscope.
	500 kg.	3,000 kg.	
Before	122	129	20
After	143	165	32

METALLOGRAPHY.

The constitution of this series is indicated in the equilibrium diagram given in Figure 2, which represents the results of the most recent investigation. It will be noted that up to about 9 per cent aluminum the alloys consist of the single alpha solid solution. Beyond this percentage a second solid solution (beta) appears at high temperatures and breaks down into a eutectoid of alpha plus delta. Little information is available in regard to the constitution of the aluminum-iron-copper alloys, but it is known that the solubility of the iron is probably very low, and when present in excess it occurs in small particles, having a blue tinge and distinctly visible in the unetched specimen, thus indicating their relative hardness. As a result of the experience gained in connection with iron in manganese bronze, it is believed that this

iron constituent consists of an iron-rich solid solution of iron and copper.

Figures 3 and 4 illustrate the structure of the 7.80 per cent aluminum alloy containing 4.15 per cent iron. Figure 3 shows grain boundaries and well-distributed particles of iron constituent which appear white with black rings. There is a small amount of delta to be found at the grain boundaries, as may be faintly noted in Figure 4. Figures 5 and 6 illustrate the structure of the alloy containing 8.49 per cent aluminum and 1.28 per cent iron. In Figure 5 the large white areas are the alpha solid solution and the dark areas are the delta. In Figure 6, due to the different method of etching, the alpha appears mottled and the delta areas clear gray. The alpha in the eutectoid formation in the center of the particle of delta appears black, due to the deep etching. The iron constituent appears in small white globules. Figures 7, 8, and 9 illustrate the structure of an alloy of 9.70 per cent aluminum and 3.20 per cent iron. The average structure is shown in Figure 7 in which the white is alpha, the dark areas sprinkled with white are the alpha-delta eutectoid, and the black specks the iron constituent. Figure 8 shows the eutectoid at a higher magnification and also shows very faintly a white lacework structure in the center of the photograph. This structure was observed in the unetched specimen and appeared similar to the well-distributed particles of the iron constituent. Figure 9 illustrates this structure in a much clearer manner. The alpha areas are dark, the delta areas white, and the iron particles a slightly brighter white. The alpha particle in the center of the photograph is nearly completely surrounded by the envelope of a white lacelike constituent referred to above. All of these microphotographs were taken from the three-fourths inch diameter end of test bars cast according to pattern TB-2B. Figures 10 to 15 illustrate the effect of rate of cooling on the structure of the test bars of the alloy containing 8.49 per cent aluminum and 1.28 per cent iron. Attention is directed to the areas in the center of Figure 12 which appear darker than the eutectoid areas in the rest of the photograph. These areas are shown at higher magnification in Figure 13. They are of the same lacework structure referred to in connection with Figure 9, but due to the method of etching it is rather difficult to distinguish this from the alpha-delta eutectoid. The arrows in Figure 13 indicate the boundary between this constituent and the alpha-delta eutectoid. Figures 5 and 10 are of specimens cast from the same original ingot and are very similar; differences in tone are due to slight differences in time of etching and of exposure in photographing and printing.

LITERATURE REVIEW.

The following articles, which were all that were available in Dayton, were reviewed in connection with this investigation.

Eighth Report to the Alloys Research Committee of the Institute of Mech. Engr. British.

This is a very comprehensive study of the binary copper-aluminum alloys made by Prof. H. C. H. Carpenter and Mr. C. A. Edwards.

Institute of Metals, Vol. X, 1913, No. 2, page 344. The Influence of Phosphorus on Some Copper-Aluminum Alloys. By Prof. A. A. Read.

This is an investigation of the effects of phosphorus on the alloys of copper and aluminum containing 1, 5, and 10 per cent aluminum.

Institute of Metals, Vol. VIII, 1915, No. 1, page 249. Some Experiments on Copper-Aluminum Alloys. By J. H. Andrew.

This paper deals entirely with the constitution diagram and is the most valuable and thorough work on the metallography of this series. The equilibrium diagram given in this report was taken from this paper.

A. S. T. M., Vol. XVI, 1916, page 118. Aluminum Bronze: Some Recent Tests and their Significance. By W. M. Corse and G. F. Comstock.

A very good paper, covering endurance tests and heat treatment in detail. It points out the superiority of aluminum bronze over manganese bronze in point of view of endurance.

Institute of Metals, Vol. XIX, 1918, No. 1, page 55. The Constitution of the Copper-Rich Aluminum Copper Alloys. By J. Neill Greenwood.

This article is an attempt to classify the metallographic constituents of aluminum bronze by Brinell hardness tests.

Institute of Metals, Vol. XIX, 1918, No. 1, page 123. Die Casting of Aluminum Bronze. By H. Rix and H. Whitaker. Also an abstract in Chemical & Metallurgical Engineering, Vol. XX, No. 3, Feb. 1, 1919.

Composition 7 to 10 per cent alumium, 1 to 4 per cent iron. Some iron and aluminum enter into solid solution with copper, forming the alpha constituent, but the bulk properly separates out as a high melting point $FeAl_3$ which forms a skeleton in which the residual metal solidifies. This refractory skeleton thus reduces the shrinkage and produces a fine grain. The iron also increases the yield point and tensile strength at the expense of the ductility. The above alloys show no alpha constituent.

Iron should be added as pure wrought-iron chips; silicon is fatal. Melted at as low a temperature as possible; melting practice is responsible for many blow holes and other defects. Bottom gating gives a flow of metal which has a cleaning effect.

Best material for dies is chilled-cast close-grained gray iron as hard as can be machined. It gives the following analyses of dies which have given satisfactory service:

Phosphorus	1.30	0.89
Combined carbon	.14	.84
Graphitic carbon	3.35	2.76
Silicon	2.40	2.02
Manganese	.43	.29
Sulphur	.10	.07

Chem. & Met. Engr., Vol. XXI, No. 15, Dec. 24 and 31, 1919. Experience with a 91-9 Copper-Aluminum Alloy. By A. I. Krynitzky.

This composition was used for time fuses at a time-fuse plant in Petrograd, Russia. He states that purity

of raw materials is important and that high aluminum rods have a tendency to fracture through cold working. The skin should always be removed before rolling and drawing. He states that machining of these alloys is not difficult.

Chem. & Met. Engr., Aug. 15, 1919, page 179. Relation of Microstructure to Phase Change in Heat-Treated Aluminum Bronzes. By L. R. Seidell and G. J. Horvitz.

Transactions S. A. E., April, 1918. Aluminum Bronzes. By W. M. Corse. Also abstracted in Chem. & Met. Engr. Vol. XX, No. 4, Feb. 15, 1919.

He states that the use of aluminum in copper alloys was discovered in 1855 by Lord Percy. The usual composition is 90 per cent copper, 10 per cent aluminum. He gives the following comparison between aluminum bronze and phosphor bronze for worm gears:

I: Phorphor bronze. Copper 88 per cent, tin 11 per cent, phosphor 0.3 per cent.

II: Aluminum bronze, Aluminum 10 per cent, iron 1 per cent, copper 89 per cent.

	I.	II.
T. S., lbs. per sq. in	35,000–40,000	65,000–80,000
Y. P. elong. 6–10/20–30	22,000–25,000	23,000–28,000
Red. of area, %	7–9	21–29
Specific gravity	8.5	7.5
Brinell, 500 kg		92–100
Shrinkage per foot	0.125	0.22
Wt. per cu. in., lb	0.31	0.27
Comp. E. L	16,000	10,000
Coef. of friction	0.0040	0.0025
Res. to impact, Fremont, 7 x 10 mm	2–4	7–10
Endurance, Landgraf & Turner	150–400	3,500–5,500
Res. to shear impact, McAdam	300–450	750–850
Mod. of elasticity	12×10^6–14×10^6	15×10^6–18×10^6

Cast aluminum bronze possesses properties equal to the rolled or forged alloys.

Bronze Mangalum No. 100. Essai 4.511.

Copper, 90.10 per cent; aluminum, 9.55 per cent; manganese, 0.28 per cent; iron, 0.07 per cent; silicon, trace; lead, tin, nickel, zinc, nil. Heat treatment: Quench begins to be effective at 700° C. (1,292° F.); but is not complete until 800° C. (1,472° F.). 900° C. (1,652° F.) seems to be higher than necessary and gives a coarse grain. Drawing temperatures after 800° C. quench: 500° C. (932° F.) begins to be effective; 700° C. (1,292° F.) most desirable. Properties after quench from 800° C. (1,472° F.) and draw 600 to 700° C. (1,112–1,192° F.). Tensile strength, 78,000 lbs. per sq. in.; elongation, 20 per cent; Charpy 8 kg. m., 56.2 ft. lb. 10 x 10 mm. spec. 1 mm. rad. notch 2 mm. deep.

Metal Industry, Vol. XVIII, No. 11, 1920, page 520. Die Casting Aluminum Bronze. By the Buffalo Bronze Die Casting Co.

Data from letter of W. H. Bassett, American Brass Co., June 25, 1921.

	5% Al.	8% Al.
Specific gravity	8.176	7.80
Wt., per cu. in	0.2954 lb.	0.2818 lb.
Wt., per cu. ft	510.41 lb.	486.94 lb.

Physical properties, 8 per cent aluminum ½ in. diameter rods:

	Tensile strength.	Elongation.
Hard drawn	100,000	2
Annealed	60,000	50

10 per cent aluminum, 3 per cent iron, 87 per cent copper.

$1\frac{1}{16}$ in. rods extruded, annealed and drawn to size. Tensile strength, 105,200; elongation, 14 per cent; R. 24 per cent.

$1\frac{5}{16}$ in. rods. Tensile strength, 99,600; elongation, 23 per cent.

Coefficient of Expansion. Bureau of Standards Scientific Paper No. 40, page 159.

92.17 per cent copper, 7.34 per cent aluminum, 0.40 per cent zinc, 0.09 per cent silicon is—

0.0000166 from 25 to 100° C.

0.0000179 from 25 to 300° C.

TABLE 1.—*Effect of methods of casting test bars—Lumen Bearing Co.*

TB-1—"AS CAST."

Specimen marked	722-1A	722-1B	722-1C	722-4A	722-4B	722-4C	Ave.
Orig. dia., in	0.492	0.497	0.484	0.483	0.500	0.494	....
Yld. point, lb./sq. in	30,240	30,930	32,070	27,290	27,500	27,860	29,315
Ult. str., lb./sq. in	67,540	69,070	74,460	75,810	66,970	71,060	70,820
Elong. in 2 in., %	21.5	21.5	25.0	29.0	23.0	25.0	24.3
Location of fract	O. T.	O. T.	M. T.	O. T.	M. T.	O. T.	....
Character of fract	Diag.	Diag.	Diag.	Diag.	Diag.	Diag.	....
Brinell, 500 kg	100	93	93	93	93	96	94.67
Scleroscope	22	23	23	23	24	23	23

TB-1A—"MACHINED."

Specimen marked	722-2A	722-2B	722-2C	722-5A	722-5B	722-5C	Ave.
Orig. dia., in	0.500	0.500	0.501	0.498	0.498	0.502	....
Yld. point, lb./sq. in	36,410	35,650	42,100	38,660	39,530	39,410	38,625
Ult. str., lb./sq. in	67,840	53,620	65,030	67,250	69,560	66,690	64,995
Elong. in 2 in., %	22.0	12.5	20.5	22.0	23.5	26.0	21.1
Location of fract	M. T.	O. T.	M. T.	M. T.	M. T.	O. T.	....
Character of fract	Diag.	Diag.	Diag.	Jagged.	Jagged.	Jagged.	....
Brinell, 500 kg	80	83	93	86	93	89	87.3
Scleroscope	26	26	27	24	23	23	24.8
Specific gravity	7.68	7.58	7.54	7.71	7.54	7.50	7.59

Table 1.—*Effect of methods of casting test bars—Lumen Bearing Co.*—Continued.

TB-2A—[illegible]-IN. WEB.

Specimen marked	722-3A	722-6A	722-8A	Ave.
Orig. dia., in	0.498	0.501	0.498	....
Yld. point, lb./sq. in	31,190	32,360	34,400	32,650
Ult. str., lb./sq. in	57,120	63,410	63,760	61,430
Elong. in 2 in., %	16.5	23.0	21.5	20.3
Location of fract	O. T.	O. T.	M. T.	....
Character of fract	Rough.	Rough.	Rough.	....
Brinell, 500 kg	86	93	86	88.3
Scleroscope	26	25	23	24.6
Specific gravity	7.62	7.58	7.56	7.59

TB-2B—[illegible]-IN. WEB.

Specimen marked	722-3B	722-6B	722-8B	Ave.
Orig. dia., in	0.500	0.500	0.501	....
Yld. point, lb./sq. in	32,700	33,610	34,490	33,600
Ult. str., lb./sq. in	67,740	64,370	65,440	65,850
Elong. in 2 in., %	25	22.5	26	24.5
Location of fract	O. T.	M. T.	O. T.	....
Character of fract	Rough.	Rough.	Rough.	....
Brinell, 500 kg	96	93	93	94
Scleroscope	25	24	25	24.6
Specific gravity	7.73	7.54	7.67	7.65

TB-2S—7-IN. RISER.

Specimen marked	722-7
Orig. dia., in	0.498
Yld. point, lb./sq. in	30,800
Ult. str., lb./sq. in	57,910
Elong. in 2 in., %	24.5
Location of fract	O. T.
Character of fract	Rough.
Brinell, 500 kg	89
Scleroscope	23
Specific gravity	7.47

Table 2.—*Tests on TB-2B.*

Added aluminum Added iron	8.0 0.0	8.0 1.7		Ave.
Specimen marked	1177-4	1180-5	1180-6	....
Orig. dia., in	0.500	0.501	0.500	....
Yld. point, lb./sq. in	15,280	23,230	24,450	23,840
Ult. str., lb./sq. in	52,410	61,630	65,900	63,760
Elong. in 2 in., %	78.0	39	49	44
Location of fracture	M. T.	O. T.	M. T.	....
Character of fract	Drawn.	Withered.	Drawn.	....
Brinell, 500 kg	35	109	124	116-5
Scleroscope	12	22	28	25
Specific gravity	7.48	7.68	7.76	7.72
Rockwell No	37	72	68	70

Added aluminum Added iron	8.0 3.0			Ave.	8.0 4.0			Ave.
Specimen marked	1192-1	1192-4	1192-5	....	1195-4	1195-5	1195-6	....
Orig. dia., in	0.501	0.504	0.501	....	0.500	0.497	0.500	....
Yld. point, lb./sq. in	26,380	29,070	28,410	27,950	28,520	28,350	27,760	28,210
Ult. str., lb./sq. in	78,830	78,290	80,150	79,090	77,510	78,300	79,450	78,420
Elong. in 2 in., %	48.0	43.0	43.5	44.8	29	28.5	45.0	34.2
Location of fract	M. T.	M. T.	M. T.	....	M. T.	M. T.	M. T.	....
Character of fract	Jagged.	Jagged.	Jagged.	....	Jagged.	Jagged.	Jagged.	....
Brinell, 500 kg	....	136	124	130	130	....	119	124.5
Scleroscope	....	33	26	29.5	31	....	26	28.5
Specific gravity	....	7.75	7.64	7.70	7.73	....	7.73	7.73
Rockwell No	....	70	76	73	70	....	72	71

Table 2.—*Tests on TB-2B*—Continued.

LUMEN BEARING CO.

Added aluminum / Added iron			Ave.	10 / 3			Ave.
Specimen marked	1175-4	1175-5	....	1213-4	1213-5	1213-6	....
Orig. dia., in	0.500	0.497	....	0.501	0.500	0.500	....
Yld. point, lb./sq. in	32,090	26,500	29,290	28,910	31,070	34,630	31,540
Ult. str. lb./sq. in	59,380	64,330	61,850	71,370	80,110	75,740	75,740
Elong. in 2 in., %	24	33.5	28.75	16	21.5	25.5	21.0
Location of fract	O. T.	M. T.	....	M. T.	O. T.	O. T.	....
Character of fract	Jagged.	Drawn.	....	Sml. flaw.	Jagged.	Jagged.	....
Brinell, 500 kg	93	109	101	....	105	130	117.5
Scleroscope	27	29	28	....	25	38	31.5
Specific gravity	....	....	....	....	7.32	7.49	7.41
Rockwell No	46	66	56	....	71	71	71

Table 3.—*Modulus of elasticity tests.*

Specimen marked	1177-7	1180-8	1192-8	1195-8	1213-8
Diameter, in	0.745	0.747	0.747	0.751	0.749
Proportional limit, lb./sq. in	7,000	14,000	18,500	16,000	11,500
Ult. str., lb./sq. in	41,870	60,280	73,950	66,170	58,960
Elong., % in 2 in	50.0	36.5	30.5	18.5	10.0
Elong., % in 4 in	49.5	33.75	28.0	17.5	9.5
Elong., % in 8 in	49.4	32.75	26,625	15,875	8.375
Reduction of area, %	53.7	34.6	32.0	28.7	16.8
Location of fract	O. S. G.	M. T.	O. T.	M. T.	M. T.
Character of fract (small flaws in every break)	Drawn.	Square.	Jagged.	Square.	Square.
Modulus of elasticity	15,380,000	15,450,000	17,550,000	16,950,000	16,530,000

Table 4.—*Charpy impact tests.*

Specimen marked No.	Impact ft. lb.	Brinell, 500 kg.	Specimen marked No.	Impact ft. lb.	Brinell, 500 kg.	Specimen marked No.	Impact ft. lb.	Brinell, 500 kg.	Specimen marked No.	Impact ft. lb.	Brinell, 500 kg.	Specimen marked No.	Impact ft. lb.	Brinell, 500 kg.
1177-1-8	76.09	45	1180-1-7	33.63	74	1192-1-7	33.63	89	1195-1-7	30.60	93	1213-1-7	13.24	100
1177-2-8	64.66	48	1180-2-7	36.74	80	1192-2-7	32.11	93	1195-2-7	30.60	96	1213-2-7	13.24	100
1177-3-8	72.26	48	1180-3-7	35.22	77	1192-3-7	32.11	86	1195-3-7	30.60	93	1213-3-7	14.39	100
1177-4-8	72.26	48	1180-4-7	40.00	80	1192-4-7	35.22	93	1195-4-7	33.63	93	1213-4-7	15.76	100
1177-5-8	70.38	45	1180-5-7	30.60	80	1192-5-7	36.74	93	1195-5-7	30.60	93	1213-5-7	14.39	100
1177-6-8	68.42	48	1180-6-7	33.63	80	1192-6-7	38.41	93	1195-6-7	30.60	93	1213-6-7	14.39	100
1177-7-8	72.26	45	1180-7-7	33.63	77	1192-7-7	38.41	89	1195-7-7	30.60	93	1213-7-7	14.39	100
1177-8-8	74.21	48	1180-8-7	36.74	74	1192-8-7	36.74	93	1195-8-7	30.60	93	1213-8-7	15.76	100
Av.	71.32	46.87	Av.	35.02	77.75	Av.	35.42	91.12	Av.	30.98	93.375	Av.	14.44	100

Table 5.—*Porosity tests.*

Cup No.	Number seconds for 1,000 c.c. to leak through. Pressure 115 pounds.	Cup No.	Number seconds for 1,000 c.c. to leak through. Pressure 115 pounds.	Cup No.	Number seconds for 1,000 c.c. to leak through. Pressure 115 pounds.
1177-1	8	1180-3	No leak.	1195-3	115
1177-2	No leak.	1192-1	48	1213-1A	35
1177-3	No leak.	1192-2	No leak.	1213-2A	15
1180-1	280	1192-3	95	1213-3A	300
1180-2	80	1195-1	No leak.		

Those cups that leaked did so in spots only, due probably to cold shuts or sand holes. The metals were good, but local flaws caused leakage.

Table 6.—*Chemical analysis.*

Melt No.	Copper.	Iron.	Aluminum (by dif.).	Zinc.	Silicon.	Tin.	Lead.
722 } 1175	89.60	1.28	8.49	0.53	0.10	Nil.	Nil.
1177	91.98	.18	7.84	....	....	....	....
1180	90.31	1.76	7.93	....	....	....	....
1192	88.80	3.22	7.98	....	....	....	....
1195	88.05	4.15	7.80	....	....	....	....
1213	87.10	3.20	9.70	....	....	....	....

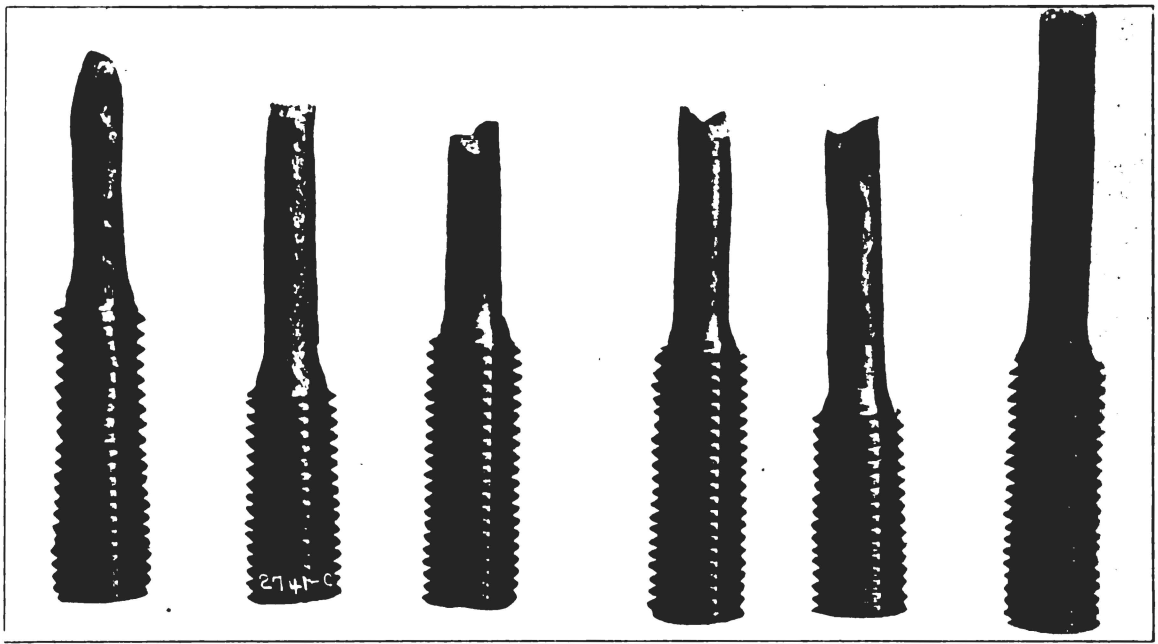


FIG. 681-1.—Fractured test bars.

	1177.	1180.	1192.	1195.	1175. Approximate.	1213.
Al	7.86	7.93	7.98	7.80	10	9.70
Fe	0.18	1.76	3.22	4.15		3.20
Cu	91.96	90.31	88.80	88.05	90	87.10
T. S.	[1] 52,400	[1] 63,800	[1] 79,000	[1] 78,420	[1] 61,850	[1] 75,740
E	[2] 78	[2] 44	[2] 45	[2] 34	[2] 29	[2] 22
Br	35	116	130	125	101	118

[1] Pounds per square inch. [2] Percent.

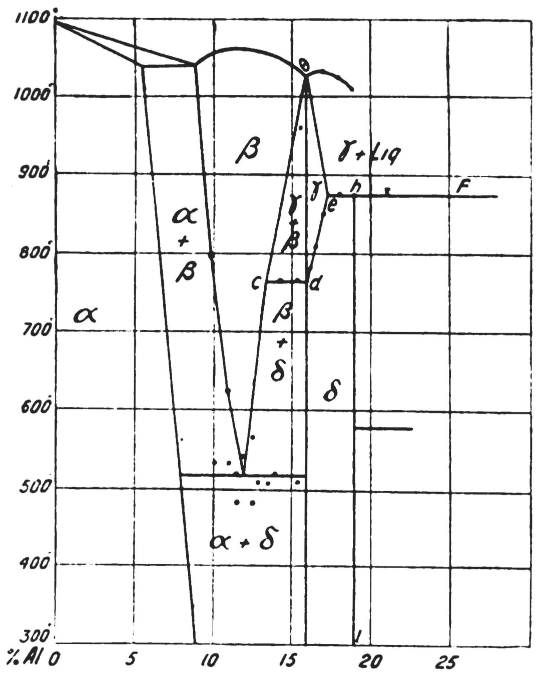


FIG. 681-2.—Constitutional diagram according to Andrew.

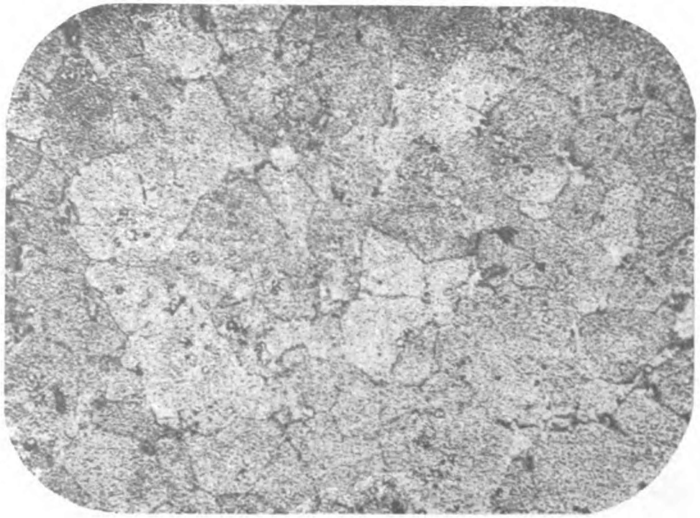


Fig. 681-3.—Magnification 100 diameters. Specimen 1195—Composition: Al 7.80, Fe 4.15, Cu 88.05. Etching: Copper ammonium chloride followed by concentrated HNO_3. Remarks: Note grain boundaries and light particles of iron constituent.

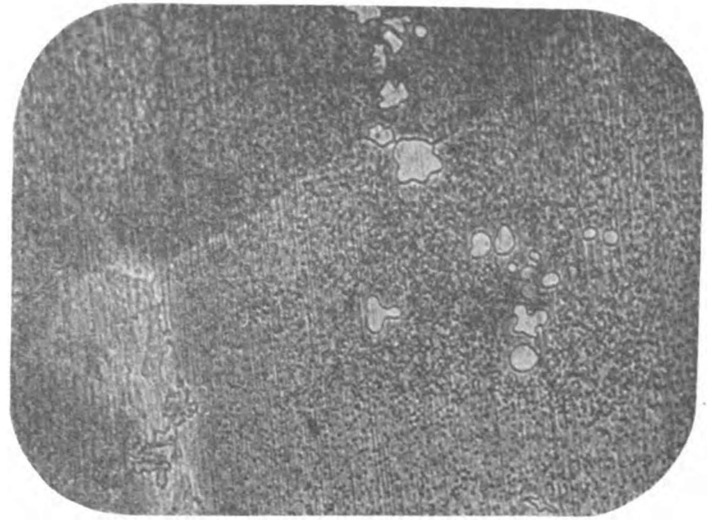


Fig. 681-4.—Magnification 500 diameters. Specimen 1195—Composition: Al 7.80, Fe 4.15, Cu 88.05. Etching: $NH_4OH + H_2O_2$. Remarks: Note trace of delta in grain boundary and light particles of iron constituent.

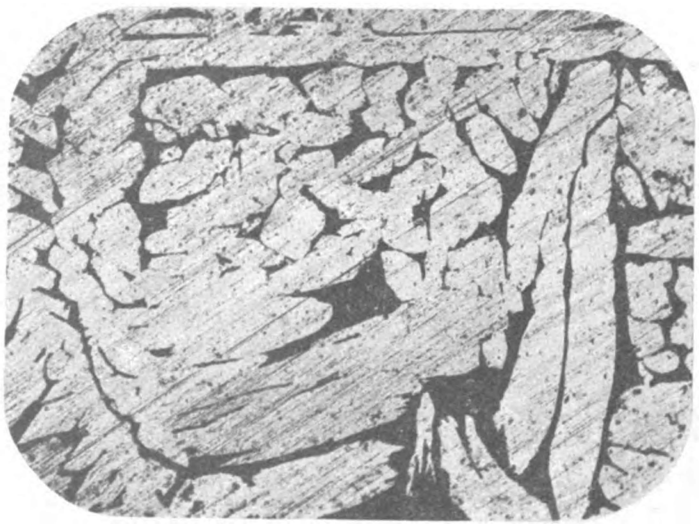


Fig. 681-5.—Magnification 100 diameters. Specimen 1175—Composition: Al 8.49, Fe 1.28, Cu 89.60. Etching: $FeCl_3$. No. 5 of B. S. S c.399. Remarks: Average structure.

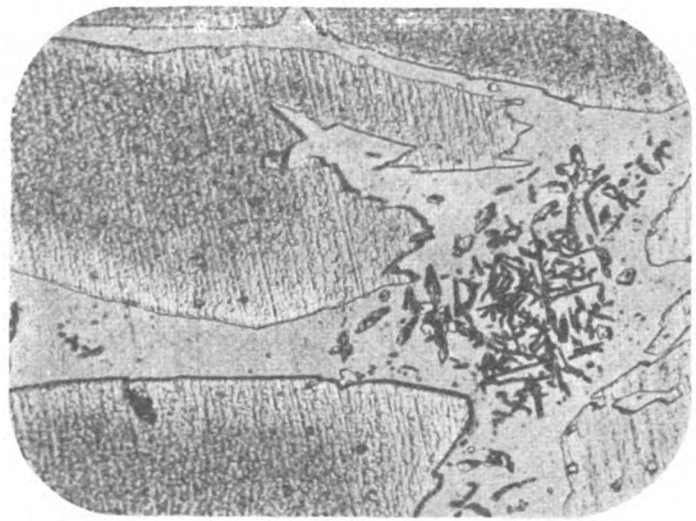


Fig. 681-6.—Magnification 500 diameters. Specimen 1175—Composition: Al 8.49, Fe 1.28, Cu 89.60. Etching: Copper ammonium chloride followed by concentrated HNO_3. Remarks: Alpha and alpha delta eutectoid with small light particles of iron constituent.

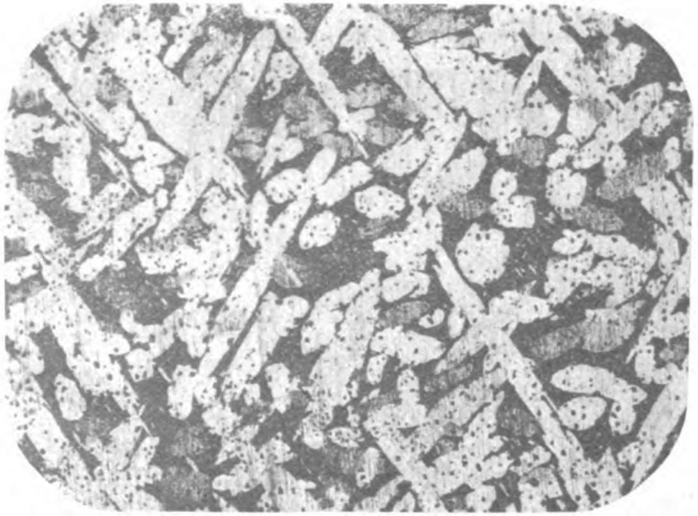


FIG. 681-7.—Magnification 100 diameters. Specimen 1213—Composition: Al 9.70, Fe 3.20, Cu 87.10. Etching: $FeCl_3$. Remarks: Black specks are iron constituent.

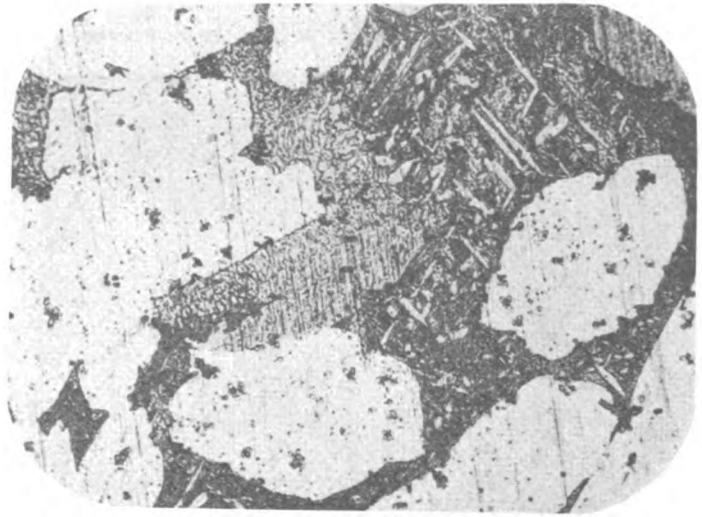


FIG. 681-8.—Magnification 500 diameters. Specimen 1213—Composition: Al 9.70, Fe 3.20, Cu 87.10. Etching: $FeCl_3$. Remarks: Note alpha delta eutectoid.

FIG. 681-9.—Magnification 500 diameters. Specimen 1213—Composition: Al 9.70, Fe 3.20, Cu 87.10. Etching: Copper ammonium chloride followed by concentrated HNO_3. Remarks: Large white areas are delta: small white particles iron constituent, and white lace work having same metallographic characteristics as the iron particles.

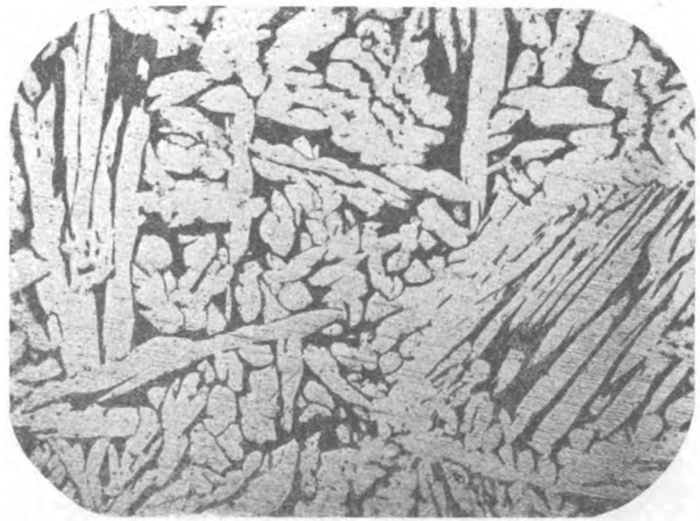


FIG. 681-10.—Magnification 100 diameters. Specimen 722-2 C. Etching: $FeCl_3$. Remarks: Structure of test bar cast according to pattern TB 1.

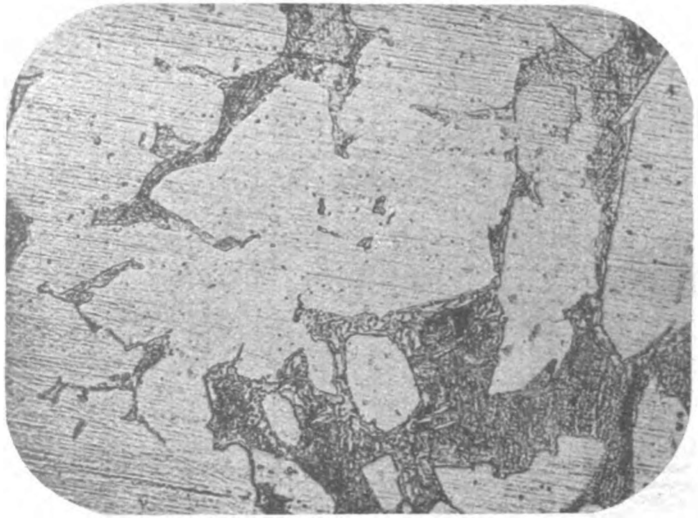


FIG. 681-11.—Magnification 500 diameters. Specimen 722-2-C. Etching: $FeCl_3$.
Remarks: Structure of test bar cast according to pattern TB-1.

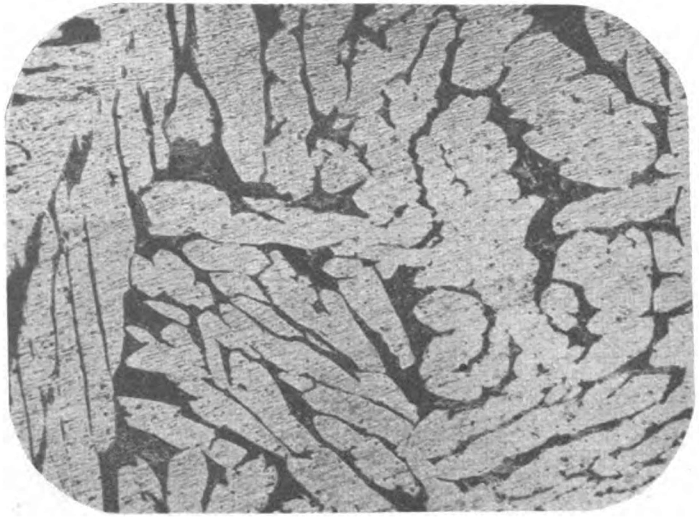


FIG. 681-12.—Magnification 100 diameters. Specimen 722-B-6. Etching: $FeCl_3$.
Remarks: Structure of test bar cast according to pattern TB-2B.

FIG. 681-13.—Magnification 500 diameters. Specimen 722-B-6. Etching: $FeCl_3$.
Remarks: Structure of test bar cast according to pattern TB-2B.

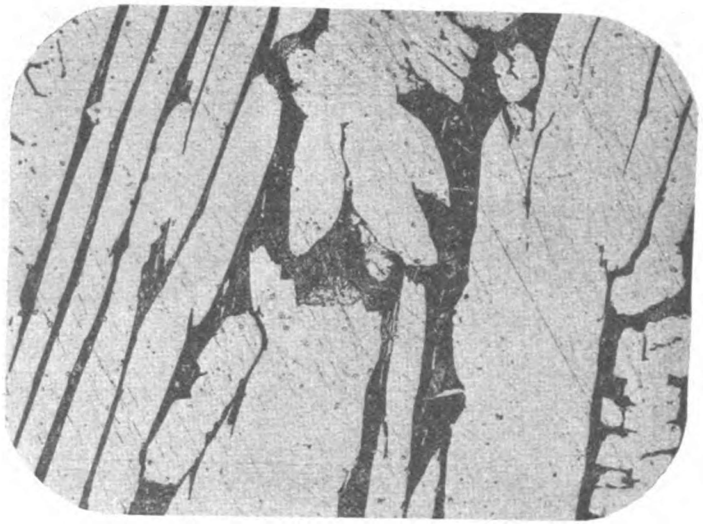


FIG. 681-14.—Magnification 100 diameters. Specimen 722-7. Etching $FeCl_3$.
Remarks: Structure of test bar cast according to pattern TB-2S.

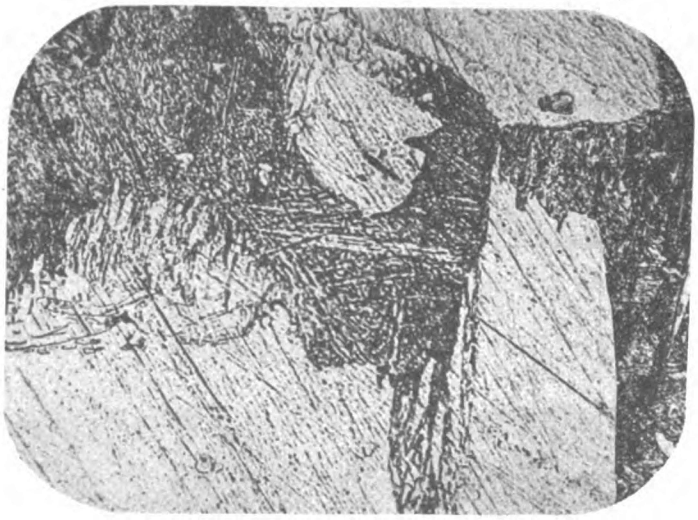


FIG. 681-15.—Magnification 500 diameters. Specimen 722-7. Etching $FeCl_3$.
Remarks: Structure of test bar cast according to pattern TB-2S.

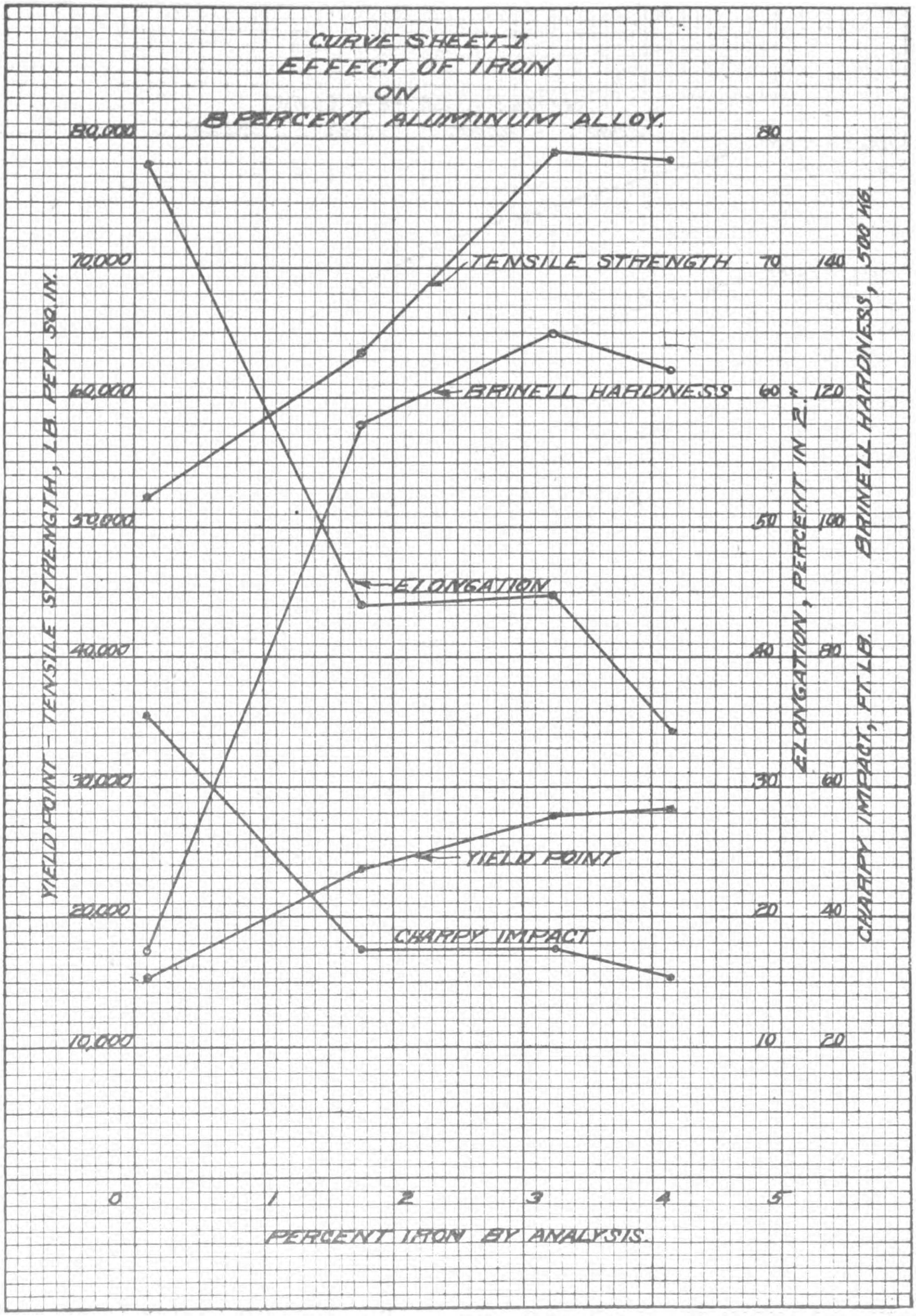
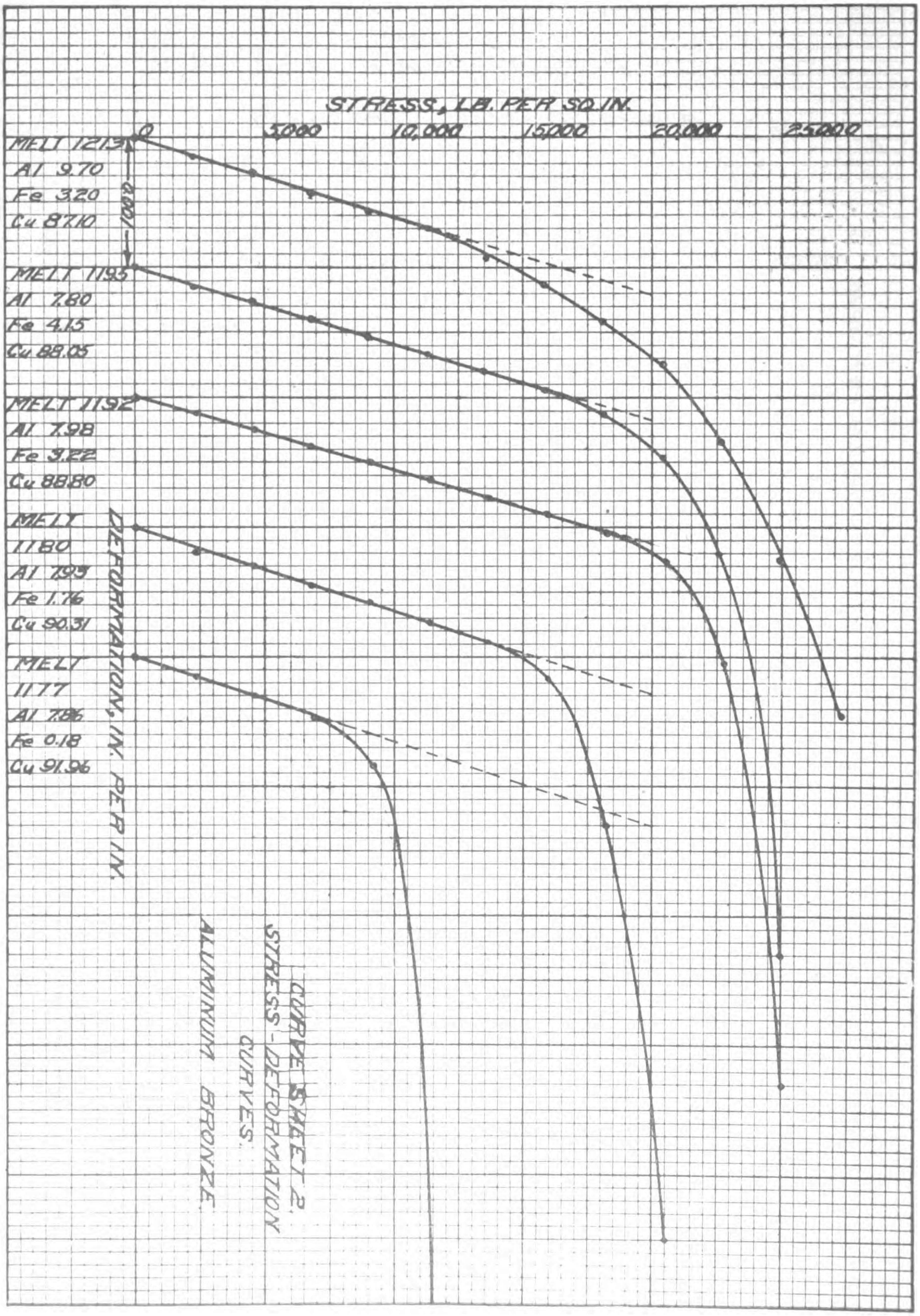

CURVE SHEET I
EFFECT OF IRON
ON
8 PERCENT ALUMINUM ALLOY.
TENSILE STRENGTH
BRINELL HARDNESS
ELONGATION
YIELD POINT
CHARPY IMPACT
YIELD POINT – TENSILE STRENGTH, LB. PER SQ. IN.
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
ELONGATION, PERCENT IN 2."
80
70
60
50
40
30
20
10
CHARPY IMPACT, FT. LB.
BRINELL HARDNESS, 500 KG.
140
120
100
80
60
40
20
0
1
2
3
4
5
PERCENT IRON BY ANALYSIS.

FIG. 16.



STRESS, LB. PER SQ. IN.
0
5000
10,000
15000
20,000
25000
MELT 1213
Al 9.70
Fe 3.20
Cu 87.10
0.001
MELT 1193
Al 7.80
Fe 4.15
Cu 88.05
MELT 1192
Al 7.98
Fe 3.22
Cu 88.80
MELT 1180
Al 7.93
Fe 1.76
Cu 90.31
MELT 1177
Al 7.86
Fe 0.18
Cu 91.96
DEFORMATION, IN. PER IN.
CURVE SHEET 2.
STRESS-DEFORMATION CURVES.
ALUMINUM BRONZE.

FIG. 17.

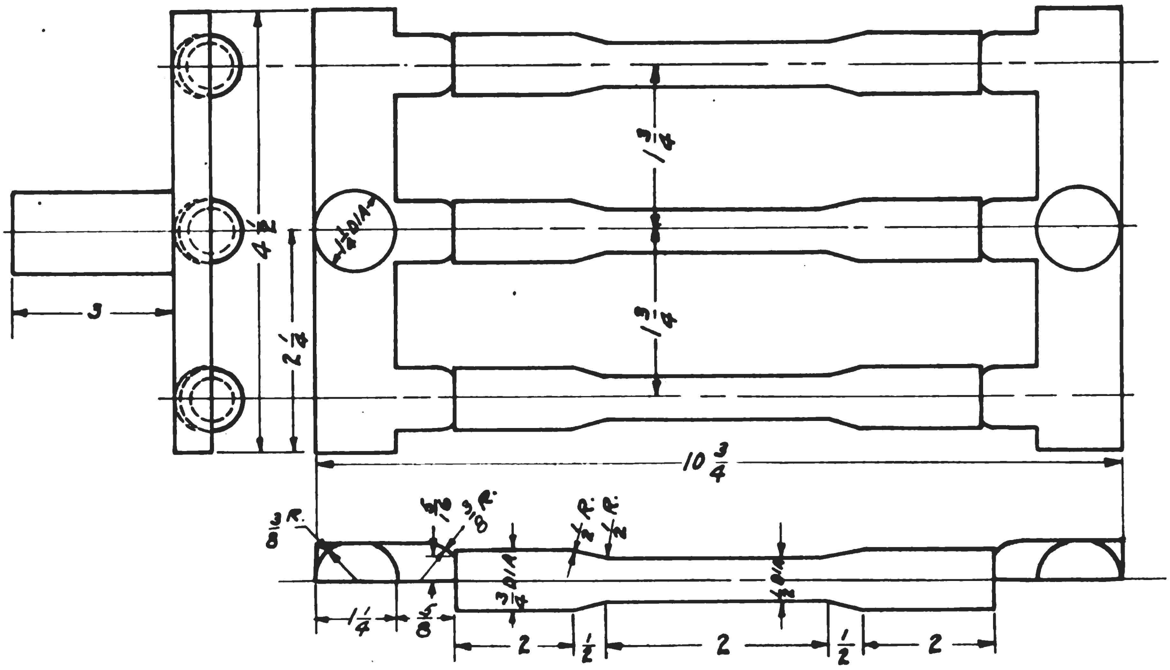


FIG. 18.—Pattern No. TB—1.

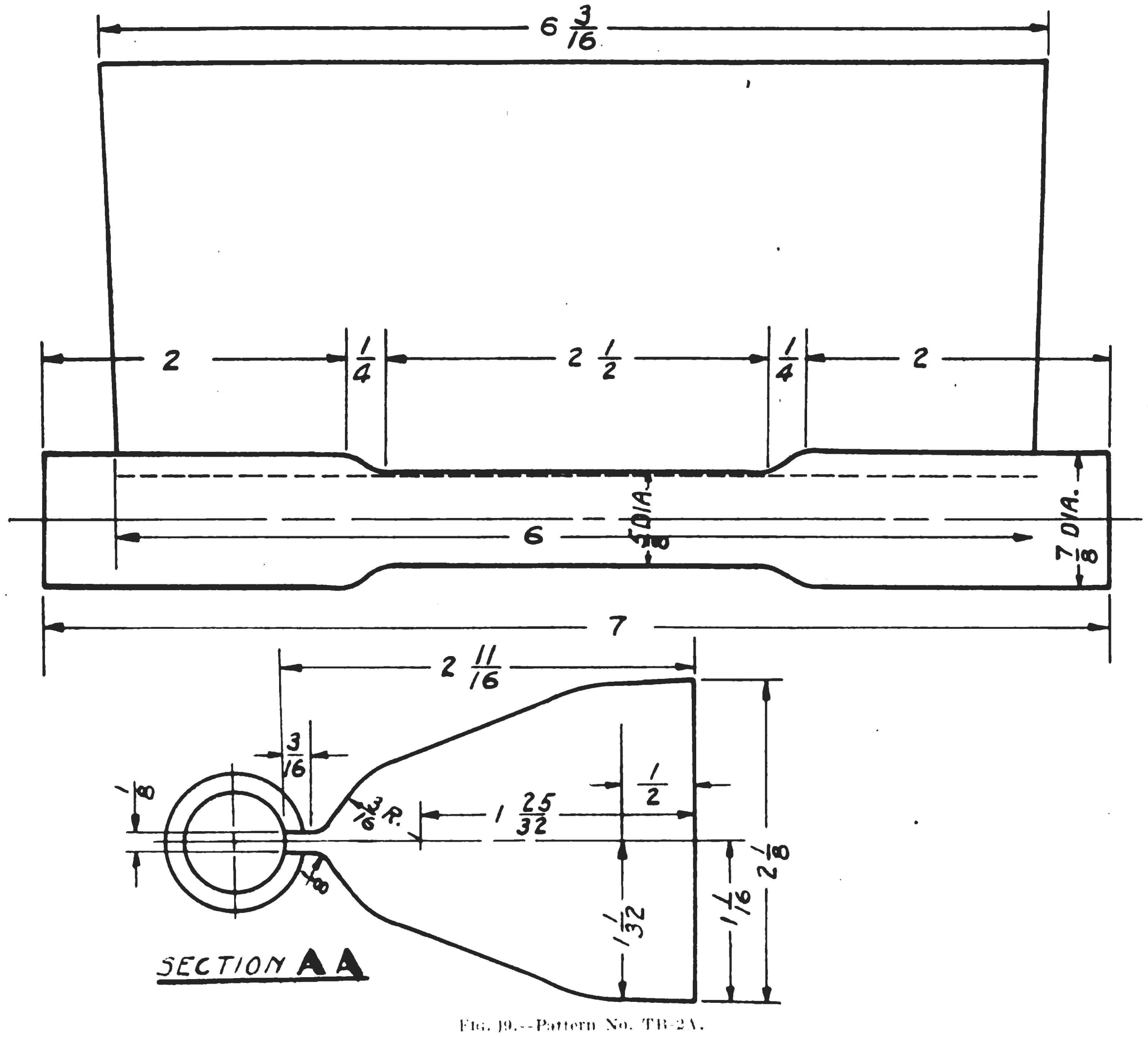


FIG. 19.—Pattern No. TB-2A.

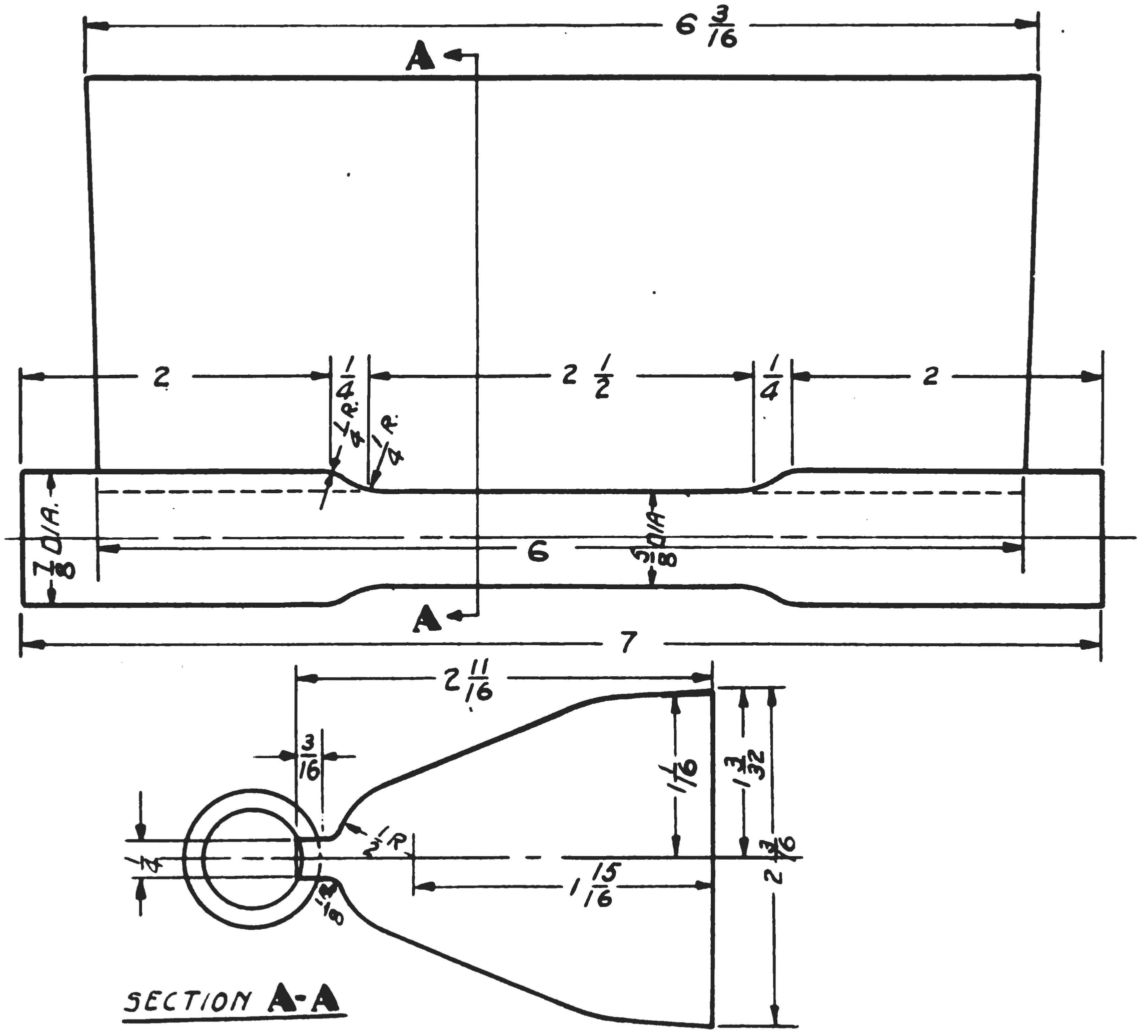


Fig. 20.—Pattern No. TB-2B.

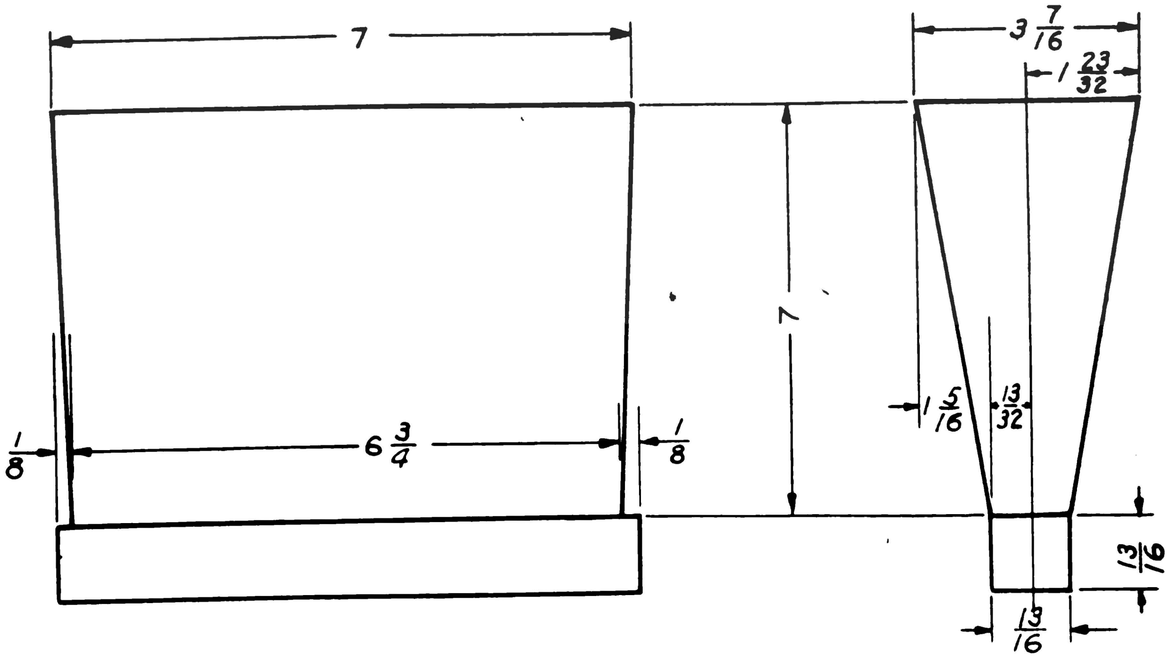


Fig. 21.—Pattern No. TB-2S.